Space Weather Sub-Group

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Outline

Reviewed and updated the three Recommendations to CGMS. Presented in order of priority.

One Recommendation within IROWG (almost unchanged with respect IROWG-8).

Recommendations within Space Weather subgroup: reviewed the ones already raised in previous IROWGs and added two new recommendations.

1. Recommendation to CGMS

Per CGMS priority HLPP 1.1.4 (optimized system for atmospheric and ionospheric RO observations), **on-going and future GNSS RO missions** (including commercial providers) should incorporate the following **key ionospheric monitoring capabilities** in their sensors: (a) **low data latency** (<30 minutes, 15 minutes goal); (b) **continuous tracks of data** spanning tangent altitudes from below 90 km up into the zenith hemisphere to the maximum extent; (c) slant TEC with 3 TECu & 0.3 TEC **absolute and relative accuracy**, respectively; (d) amplitude and phase **scintillation indices**; (e) **high rate** (50Hz or higher, as dictated by the GNSS signal being observed) observations at ionospheric tangent altitudes when scintillation is present.

When considered as a whole, **RO systems should make ionospheric measurements with approximately uniform geographic and local time coverage over the globe**.

Recommendation to CGMS

2.

Non-RO missions that fly GNSS receivers for precise orbit determination should make available to the operational and research communities all necessary level-0 data and metadata required to **produce accurate overhead TEC data**.

The GNSS data and metadata should include dual-frequency code and phase measurements, antenna phase center variations, spacecraft attitude orientation, and solar array motion. The data should have sample intervals (1 sec) and low latency if possible (goal of 15 minutes).

Recommendation to CGMS

3.

All RO data providers should make **level-0 data available** together with appropriate documentation and software to read this data, to enable science users to process the data into higher level products

Recommendations within IROWG

IROWG should continue to explore approaches for reducing ionospheric residual errors in neutral atmospheric retrievals. Success in this challenging area of work would both improve the upper altitude limit and errors of useful neutral atmospheric products. This would mostly benefit climate applications. Next steps forward should include:

(1) Further assessment of recently proposed approaches to reduce residual large-scale ionospheric errors based on the correction term that depends on the electron density distribution (e.g. the "kappa" technique)

(2) Further assessment of recently proposed approaches to reduce residual small-scale ionospheric errors (based on back propagation techniques, ray tracing, or other);

(3) Development and use of new ionospheric re-analyses in neutral retrievals to assess possible benefits;

(4) Determination of ionospheric model accuracy requirements that, if met, would likely lead to a reduction in ionospheric residuals;

(5) Evaluation of existing datasets to determine the degree to which current ionospheric residuals conform to known aspects of ionospheric climatology.

It is noted that progress updates on (1) above were presented at ROMSAF-6/IROWG-7/IROWG-9.

Recommendations within Sub-Group

1. **Encourage development/improvement of ionospheric data assimilation models** to take full advantage of the FS7/C2 and other GNSS RO data (also from commercial providers) for specification and prediction of the low latitude ionosphere, including both its large-scale properties such as the F-layer and bottomside, and small-scale properties related to ionospheric scintillation effects. These new data sets from FS7/C2 Equatorial can be expected to lead to significant advances in the state of the art of ionospheric assimilative modeling, and associated improvements to operational space weather systems, if model development efforts are adequately funded.

2. The IROWG encourages the **development of more accurate 1DVAR retrievals of ionospheric electron density profiles**. Progress in this area of research was presented at ROMSAF-6/IROWG-7 and also more recently.

3. **Coordinate with space weather activities throughout WMO**, particularly the expert team on Space Weather. Whenever possible, members of each of these teams should attend each other's meetings.

Recommendations within Sub-Group

4. Verify that the **WMO OSCAR database properly documents** the abilities of current and future missions to obtain ionospheric data per Recommendations to CGMS #1-2 above. Capabilities of both RO missions and missions flying dual frequency GNSS receivers should be documented in sufficient detail to understand the ionospheric products. The information in the database for each mission should include the extent to which the mission collects ionospheric profile and overhead TEC data, the mission data latency, and the extent to which ionospheric scintillation data are collected. In engaging with the WMO Space Weather expert team, we should request their help in this verification.

5. It is desirable to continue to **expand the sub-group membership** in the areas of **personnel associated with operational space weather support centers** and **members of the international science community** involved in the development and evaluation of assimilative ionospheric and scintillation models. Team members should advocate for travel support from operational space weather support centers that will enable scientists to support future IROWG meetings.

Recommendations within Sub-Group

6. Space Weather sub-group team members should continue **to advocate for and support greater incorporation of ionospheric radio occultation science topics** (such as the development of space weather data assimilation models) within existing ionospheric science venues such as AGU, AMS, CEDAR and IRI workshops. Collaborations within the sub-group membership involving evaluations of ionospheric models using GNSS RO data, or development/refinement of ionospheric or scintillation specification models using GNSS RO data sets, are also encouraged.

NEW RECOMMENDATIONS FROM IROWG-9

7. **Undertake studies which address the necessary occultation density and latency to achieve certain levels of specification accuracy with assimilative models.**

8. Investigate the possibility of determining accurate thermospheric density from GNSS receiver tracking data. (UCAR is doing this)